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MODERN INTEGRATED MANUFACTURING: INTEGRATION AND COMMUNICATION STRATEGY

by

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This thesis is accepted and approved in partial fullfillment of the requirements for the degree of Master of Science.

May 14, 1986
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I dedicate this thesis to my parents, Mr. & Mrs. Rajendra Prasad.

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ABSTRACT

Modern Integrated Manufacturing (MIM) encompasses the entire spectrum of manufacturing activities from design to production to distribution to aftersale service and support in the field. Hence, total integration should include Computer-Integrated Manufacturing (CIM), Just-in-time (JIT), and Total Quality Control (TQC). A well planned strategy can help tackle total integration in a structured and controlled manner. Integrating automated work-cells, and business functions using a systems approach, can result in an increase in productivity, higher return on investment, better monitoring, and an increase in the company's competitive edge.

Networks can play a vital role in this integration. Currently many manufacturers are actively involved in implementing networks in their factories. The lack of a widely accepted communications standards has led General Motors to assume a leadership role and to propose their Manufacturing Automation Protocol (MAP) as a standard.

The purpose of this thesis is to explore these integration and communications issues within manufacturing. The role played by General Motors' Manufacturing Automation Protocol will also be discussed.

Chapter 1
INTRODUCTION

Since the turn of the century, the United States of America has been one of the most productive nations on earth. America's leadership position has been partly due to "Yankee ingenuity", and partly due to the willingness to experiment. Somewhere along the way America seems to have lost its ability to look towards and work for the future. Businesses became more concerned with short term profits and did not invest in new manufacturing facilities. Unions, interested in higher wages, failed to pressure management into keeping up with the latest in technology. This lack of foresight has cost American manufacturers dearly. European and Japanese companies, sensing America's vulnerability, launched their attack in the late 1960's. Confident of their position, American manufacturers remained nonchalant.

Historically, the success of American industries has been largely due to the innovative people behind them. According to an Arthur Young & Co. study, more than 82% of the executives from Fortune 1000 companies saw the need for innovative management skills, and yet fewer than half of them were willing to try new ideas [8]. With respect to manufacturing technologies, the problem is that new concepts tend to intimidate and confuse most managers. Compounding this problem is the fact that most of these technologies are computer based, and older managers and engineers are not well-versed in this area. Many firms feel that foreign competition is biting into their market share only because of cheap labor and government subsidies. As compelling as those arguments might be, US managers have to accept their share of the blame. Their lack of foresight and leadership has contributed significantly to the current crisis. It is time for managers to change their attitudes fundamentally in order to remain competitive. Talented managers have perceived the future and provided the necessary leadership. Managers from innovative companies, such as GM and IBM, recognized the benefits of advanced technologies early and built "state-of-the-art" manufacturing facilities. These companies have installed robots, lasers, and other sophisticated machines and achieved increased productivity, reduced inventory, and increased production flexiblity [7].

Firms wanting to follow in the footsteps of these innovative and sucessful companies should start by developing an overall strategy appropriate to their business. It is important to avoid the pitfalls encountered by the forerunners. Instead of creating islands of automation, companies should treat their entire manufacturing and business operations as a single entity. Companies should also realize that there is no widely accepted methodology for developing a strategy.

This thesis examines the communications and integration issues within manufacturing and suggests a possible methodology for the development of a strategy. Communications play an indispensible role within integration and hence the role of networks and General Motors' Manufacturing Automated Protocol are also discussed.

Chapter 2
MANUFACTURING

Manufacturing, a cornerstone of America's industrial might, has been facing serious competition from the Japanese and the Europeans. Robots, lasers, sensors, machine vision and computer-aided manufacturing have been touted as the answer to American manufacturers' woes. Technology Management Center, a Philadelphia based organization, has concluded, after an 18-month study of 90 small and medium sized Pennsylvania companies, that U.S. industry has done very little in the way of modernization [10]. Advanced technologies that could improve productivity, quality and market share are largely ignored. According to the study, only 10% of the firms had any plans for introducing computers or other forms of advanced technology into their companies.

Many companies that have implemented computers have done it in an ad hoc, if not haphazard, manner. Lack of integration and coordination results from multiple causes. One cause is the traditional organizational structure of a company. Generally, every manufacturing facility can be divided into four subdivisions [4]:

- Manufacturing planning and control
- Product and Process definition/Engineering
- Computer-aided manufacturing, robotics
- Business management (marketing, finance)

Manufacturing planning and control encompasses areas which include inventory control, shop loading, capacity planning, and master scheduling. Most of the software (run primarily on IBM hardware) has been developed by third parties and sold as a package of "integrated" software modules. Instead of buying all modules from one vendor, however, most companies try to implement different modules from different vendors, and develop many other components in-house in order to perform additional functions. Modules within a package are well integrated, but functions performed outside of the package are often difficult to integrate since vendors rarely provide the source code, or even details on interfaces. This results in a system that is not and cannot be totally integrated.

Process and product definition is concerned with design and manages data concerning drawing changes, configuration management, technical specifications, bills of material, engineering data sets and NC data sets. It is not unusual for manufacturers to have five to ten different types of part numbers, and two group technology coding systems. Rarely do all of the software packages supporting these critical functions run on the same computer system.

Computer-aided manufacturing, robotics, NC/DNC/CNC, and automated material handling systems are the concern of manufacturing engineering and are even more heterogenous than product and process definition. There is virtually a complete lack of co-ordination between the two engineering functions, and hence duplication of effort is very common. Since very few vendors deal in both areas, they are unable to provide integration externally.

Lack of co-operation between individual entities has resulted in under-utilization of capital funds, duplication of efforts, and less-than efficient operation. This costly situation can be avoided if management develops an overall strategy for the entire organization. The ultimate goal is the integration of marketing, manufacturing, and after-sales support. Hence, the maximum benefit can be achieved by developing a single strategy.

Chapter 3
IMPLEMENTATION STRATEGIES

Success on a project is largely dependent on the amount of planning work put into it. If a company expects to succeed in achieving integration, then it must develop a strategy. Such a blueprint makes individual tasks and responsiblities clear. A methodology employed for the development of business systems can be adapted to the manufacturing environment. The methodology involves the following steps [1]:

- Obtain informed upper management support.
- Set up task force with representatives from all affected groups.
- Study requirements and analyze data flow.
- Research vendors, products, and technology.
- Decide implementation schedule.

3.1 Management Support

Getting the support of top level management is the most difficult task. In order to obtain their support, a solid program covering strategy and planning, vision, scope, organization, justification, exposure, education, and training, should be put together.

Strategy and Planning: Thinking of manufacturing more strategically is the key to obtaining support for Modern Integrated Manufacturing (MIM). Lower-level managers should present their goals in terms of end results, such as competitive advantage, instead of presenting it in technical terms. Achieving competitive advantage is always the top priority. A framework to view the relationships among strategies (business and internal functions), the means to achieve strategic objectives, and the tools necessary to achieve those objectives should be developed.

Many managers focus too much on "how-tos" and the tools without any understanding of the actual strategic objectives or the business strategy they are supporting. Current MIM plans, based on the bottom-up model, lack a way to strategically prioritize the selection and implementation of MIM tools. Developing an MIM plan using a top-down approach ensures that prioritization of MIM projects is done with an eye towards obtaining the greatest stragetic leverage for the company. Basically, the two critical parts of an MIM planning exercise are to create a planning frame of reference and to obtain commitment for the MIM plan from all of the company's senior management. Obtaining support for MIM implies making sure that each functional manager understands the implications to his/her department of implementing the plan. A manager who is educated and aware of these implications on a corporate-wide basis, would be willing to implement each without further delay. Obtaining this commitment will be time-consuming, but managers should be given time to understand the implications. In addition, no artificial deadlines should be set.

Vision: Currently no standard definitions for CIM, TQC, JIT or MIM exist. Therefore, it is essential for company personnel to think about and discuss these concepts. It is essential to have a technological vision of what manufacturing should look like. A technological framework should be adopted, and such a vision must be agreed upon and communicated to all company personnel. Then a standard framework and vocabulary to use in MIM planning and implementation will be known to everybody involved. This will reduce confusion.

Scope: The same idea on the scope of manufacturing must be shared by everyone in the entire spectrum of manufacturing. CIM must be viewed as a part of computer-integrated business.

Organization: Emphasis on the human aspects of MIM should be increased. People devise and implement strategies and people make systems and businesses work. Better results from individuals can be achieved by following three steps. First, one individual should be responsible for putting together the entire MIM picture. This individual, usually a Vice-President, should be responsible for monitoring the progress on the implementation effort. The line managers should be responsible for actual implementation. Second, incentives, rewards, and performance and measurement systems must be refocused so as to collectively reinforce the MIM goals. Third, new engineers who are more comfortable with the latest technologies must be hired. At present, it takes many years to find, hire, move and train new company employees.

Justification: Focus should be centered on total product cost per employee. The old approach of process-in-time is not useful anymore. Product development time should be included because it has a significant impact on product introduction and success.

Exposure: Exposing senior management to some of the "state-of-the-art" technology is also useful. Senior management should tour their own facilities and compare them with some other progressive companies' facilities. They should also visit some modern MIM showcases. Exposure to trade shows and plants in Europe and Japan would also help.

Education & Training: Another important aspect, if MIM is to be successfully implemented, is Education and Training. Technology is changing rapidly and on-going training is crucial. Companies that don't spend money on training and education will never be competitive. People resist changes due to lack of knowledge. Education and training can overcome this problem.

It is very important that everyone, from the chairman of the board down to the workers on the floor, is committed to MIM, or else the results will fall below expectations. Implementing parts of MIM will lead to less-than-intended success. Senior management should realize that anything less than a full-fledged commitment is of no use. The result of this exercise should be a well-planned and well-understood blueprint for the future. At this point a good planning document should answer three basic questions :

- Where do we stand today with regard to our manufacturing capability ?
- Where do our worldwide competitors stand today with regard to their manufacturing capabilities ?
- What proven roads exist (technologies, principles, pratices, philosphies) to get us from where we are today to where we'll have to be in the future to maintain competitive advantage in the world markets ?

The development of a good planning document will result in the support of upper-level management.

3.2 Task Forces

Once the planning document has been developed, task forces should be set up. These groups should be composed of members from the different departments that would be affected. Each individual should have a fairly good knowledge of the activities of his/her department. The reason for setting up such task forces is the wide range of technology involved. Obviously, everybody cannot be an expert in all fields. Setting up task forces ensures in-depth analysis of the different components of integration. Each task force should be reporting to senior management, in order to keep the "whole picture" in perspective.

3.3 Study Requirements and analyze data flow

Each task force should work on different components of the project. Conducting a detailed investigation could bring out new and possibly suppressed information which could be vital to the operations of the business. Identification of current devices on the shop floor, such as machines, robots, and programmable controllers is crucial. In order to integrate devices, the communications capabilities and requirements of each device have to be analyzed. The study should provide a detailed picture of the current status of the company's facilities and the requirements for the future.

Analysis of data flow helps in evaluating the relationships that exists among the different entities of the organization. Modelling of information flow is very important because all the messages which are "moving around" the network must be managed. Modelling can help improve data integrity. For example, if a bill of material system resident on an IBM system is updated, this update should be reflected on all other applications dependent on that system. Such relationships would be evident by modelling information flow.

3.4 Research Vendor, products, and technology

Technology is changing at a rapid pace, and there are new products being introduced on a daily basis. It is very important for the task force members to be knowledgable about the products currently in the market. Vendors are a good source of information. As is the case with any purchasing decision, the vendors must be throughly researched and questioned. One should not be afraid of asking tough questions, and should double-check information given by the vendor. Fully integrated facilities should use automated process planning, computer-aided design, an automated quotation system, group technology, a factory management system, and networks [2]. Communications technology is at present evolving and therefore is difficult to manage. Networks and Manufacturing Automation Protocol (two of the hottest issues at present) are examined further later in this thesis.

3.5 Implementation

Implementation involves more than just the physical placement of machines. It involves user interfaces, implementation of necessary software, and creation of appropriate databases. Creation of an integrated database that is timely, consistent, and accurate is very important since information is the key to success in today's market place. Data has to be standardized in order to accomplish this. Data cannot be invented "on the fly". Data is to the information environment as a part is to the engineering/manufacturing environment. Efficiency, economy and flexibility are gained through re-use, not re-invention. Data standardization is accomplished by defining and building a set of rules. These rules define entities we need to store data about, the data we need to store about these entities, and the constraints on the relationship that exists among the entities and their data. These rules are interdependent, and a significant part of the problem is consistency. Rules must be developed to ensure consistency as new application databases are built or bought. Without data consistency, there is no hope of achieving data integration. In many current environments each "island" has its own user interface, its own programming language, databases, graphics utilities and so on. Truly integrated systems must have one standardized language to access data anywhere in the system.

The implementation schedule should take into consideration the current and future requirements. This implies a careful coordination among the departments involved. If this is the first project in this area, then time estimates should be conservative.

This proposed strategy is just a starting point. In order to fully succeed in this venture, a company should keep constant track of the market place and take the necessary corrective actions.

Chapter 4
NETWORKS

4.1 Definition

Total factory automation, referred to as the "factory of the future", is being made possible by parallel advances in both computer and communication technology. During the early years of the "computer age", computing power was concentrated at one location. Terminals with no "intelligence" were connected to the central computer. Breakdown of the computer caused the whole system to come to a standstill. Due to the high cost of the computers, distributing the computing power via multiple computers was unthinkable. Recently, rapid advances in computer technology have led to the decrease in computer prices and a consequent proliferation of micro-computers. Interconnection of these distributed computers via transmission/communications media is defined as a network, ie: an interconnected collection of autonomous computers is said to be a computer network.

Local area networks (LAN) are a subset within networks. They are classified as "a communication network that provides interconnection of a variety of data communicating devices within a small area" [16].

The geographic scope of a local area network is small. It is usually confined to a single building or campus. In contrast, long-haul network stretches across several hundred kilometers. Figure 4-1 shows the relationship between local area networks and long-haul networks. Local area networks are generally owned privately: ie, by a company or institution. Typical characteristics of a local area network are [16]:

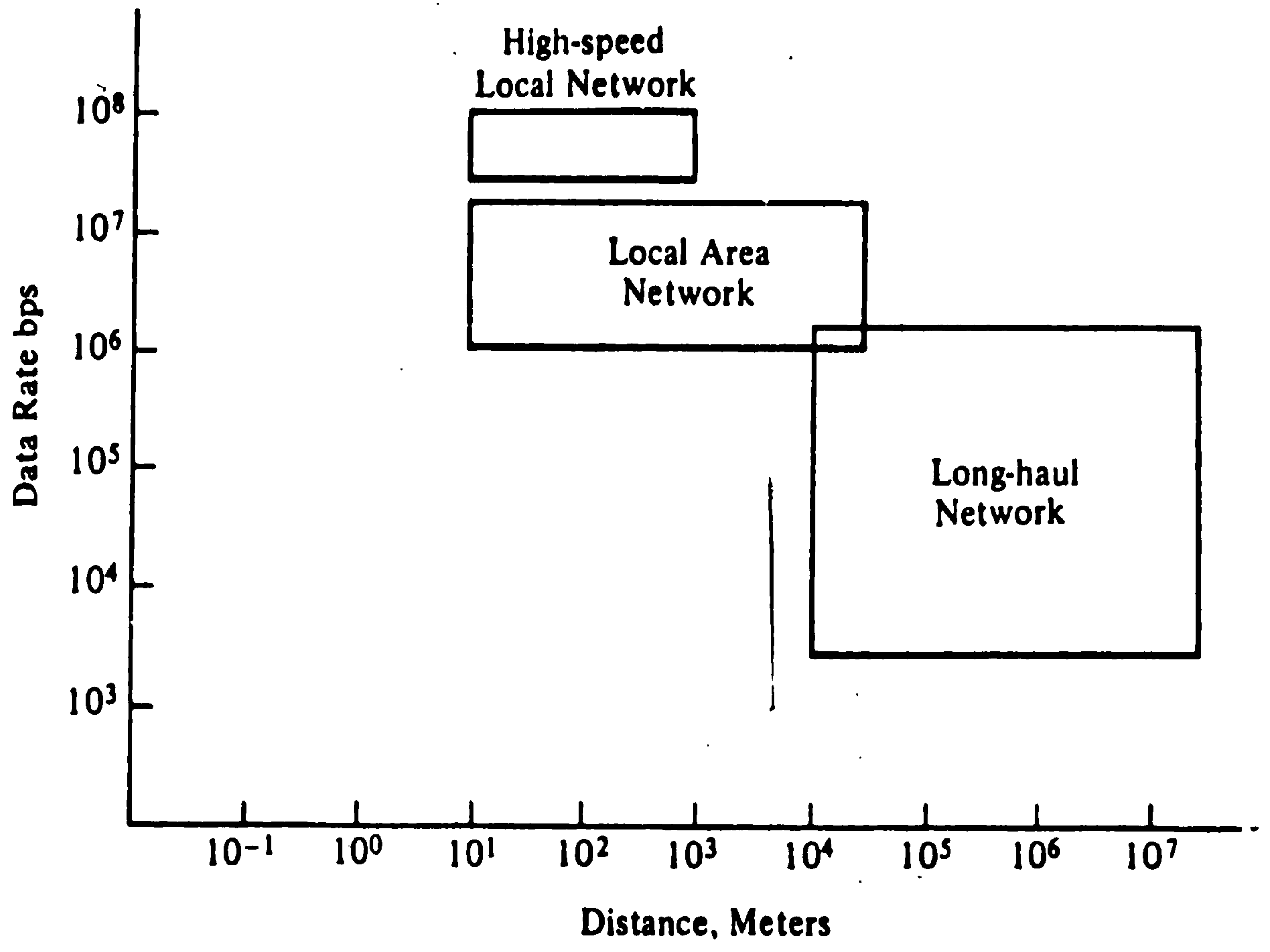


Figure 4-1: Local area-network vs long-haul networks [16].

- High data rate (0.1 to 100 Mbps)
- Short distance (0.1 to 25 km)
- Low error rate(10 * -8 to 10* -11)

The potential range of applications for local area networks is wide. Factory automation, office automation, and data processing are some of the areas where LANs have been implemented. The primary concern here is factory automation.

4.2 Goals

Companies are increasingly replacing centralized computerized systems with networks. There are two main reasons for this trend. First, many organizations already have a substantial number of computers in operation, often located far apart. Many companies have a computer operation at each location to process routine activities such as payroll, inventory. Since each computer system worked independently of the others, the individual maintenance overhead was prohibitive. Also, this isolation prevented management from obtaining up-to-date information from their facilities. By implementing a network, all programs, data and other resources become available (in principle) to anyone on the network, regardless of the physical location of the resource and the user.

The second reason is to provide high reliability and availability by having alternative sources of supply. Without a computer network, a hardware failure at one facility would leave the local users without any alternative, even though there might be substantial computing capacity available at other facilities. Implementing a network ensures continuing access to computing power. A well laid-out network design will also accomodate network failure.

A useful by-product of setting up a LAN for the above reason is the establishment of a powerful communications medium among widely separated people. Individuals working at facilities separated by large distances can still access critical and non-critical information on a real-time basis, instead of having to wait several days for a report. This instantaneous access to information will allow people to work together even if they are physically separated.

4.3 Network Structure

Machines that run user (application) programs are called hosts. The hosts are connected by a communication subnet. A subnet is responsible for carrying messages from host to host. There are two basic components in a subnet: switching elements, and transmission lines. Switching elements are called Interface Message Processors (IMPs) and transmission lines are refered to as circuits [17].

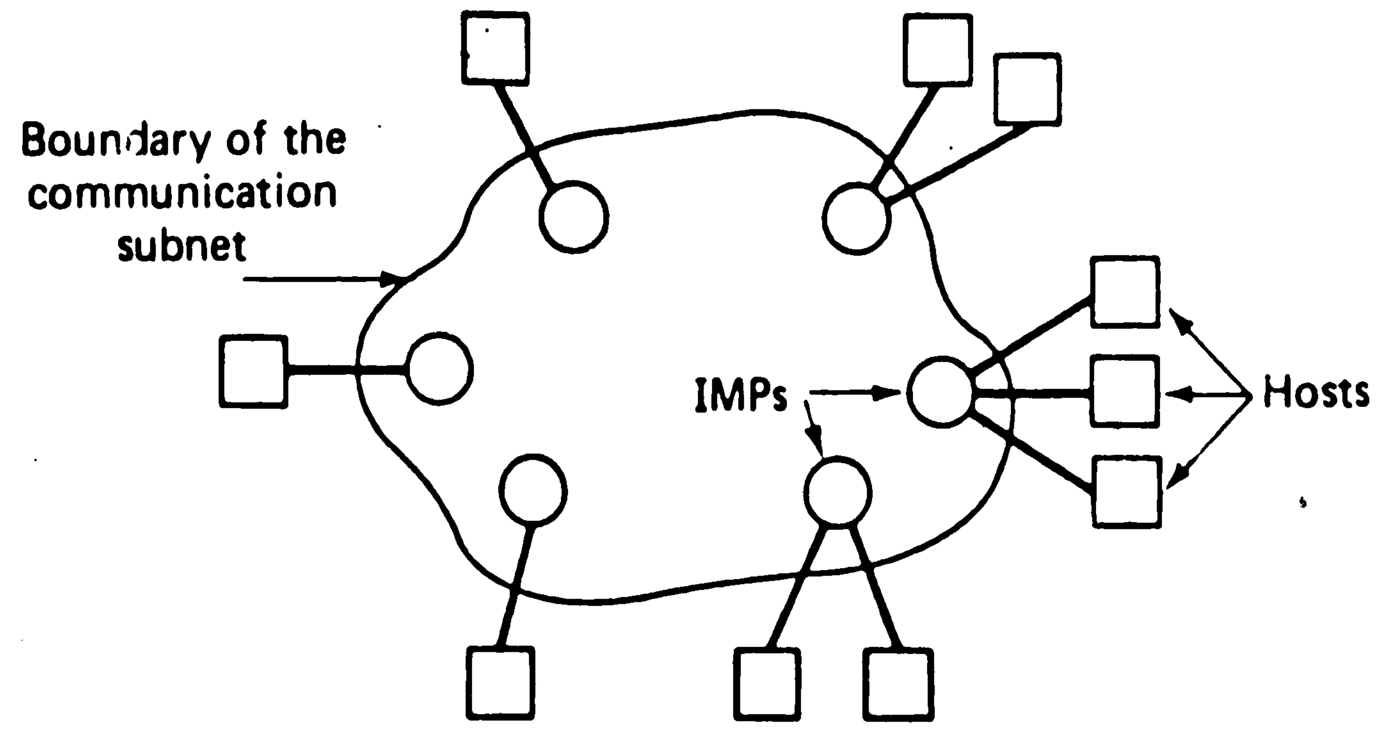


Figure 4-2: Relationship between hosts and subnets [17].

4.4 Network Topologies

Network topology is defined as the physical arrangement of computer resources, remote devices, and communications facilities.

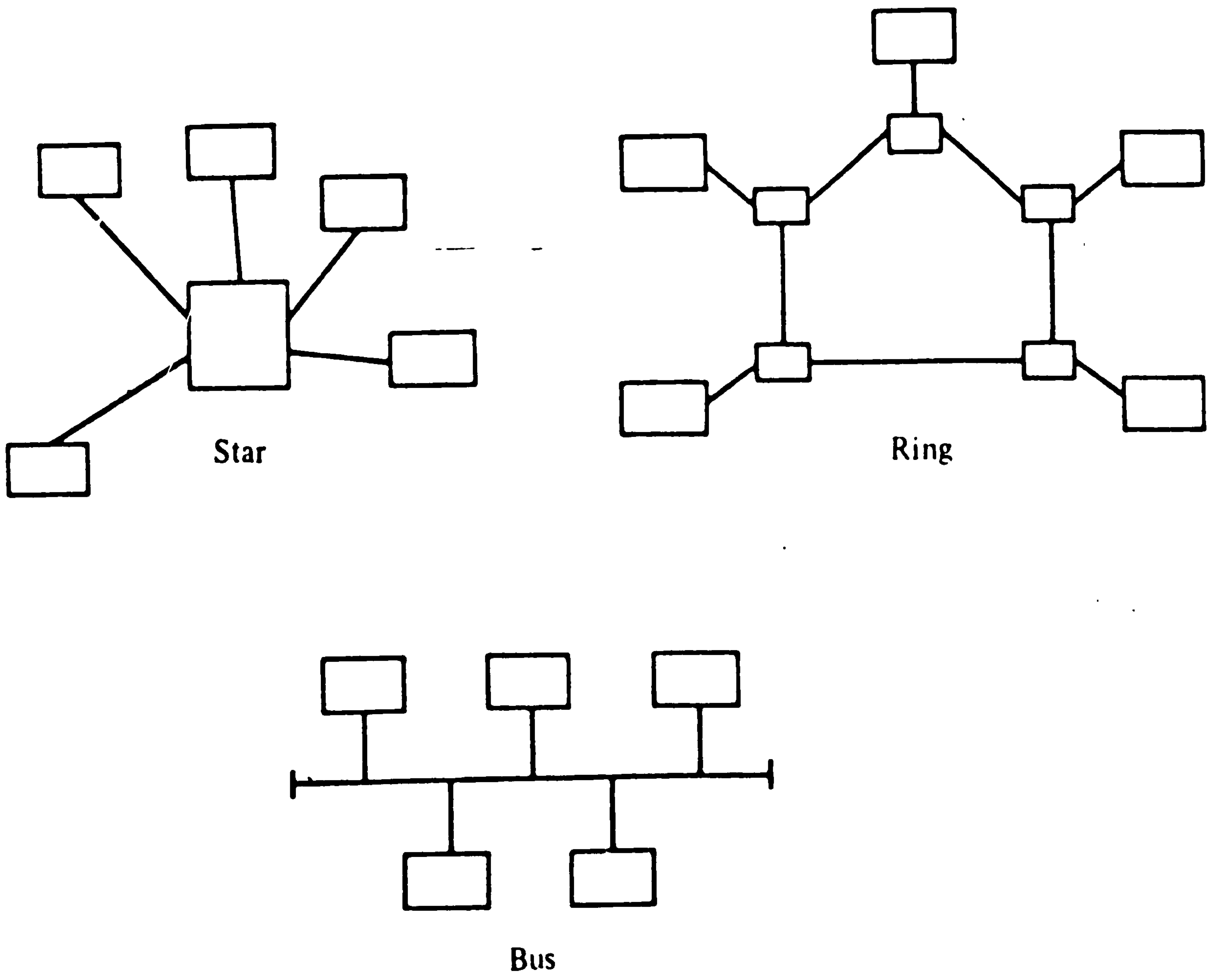


Figure 4-3: Local Area Network Topology [16].

The topology of a network is determined by the following criteria: functional objectives, reliability requirements, and operational costs. Unlike long-haul networks, LAN's have a specific topology under which they operate. Some of the most common LAN topologies are the ring, the star, and the bus (see Figure 4-3).

In ring topology, the network consists of a series of repeaters joined by a point-to-point link in a closed loop [12]. Each repeater is therefore connected to two other repeaters. The links are unidirectional: data circulate around the ring in one direction.

In contrast to a ring topology, each station in a star topology is connected by a point-to-point link to a common central switch. The central switch maintains a communications link. For a station to transmit data, it must first send a request to the central switch asking for a connection to some destination station. After the circuit has been set-up, exchange of data between the two stations can take place freely.

A bus topology consists of a single mainline from which individual stations branch off. This tree-like structure is well-suited to a manufacturing environment because the layout is similar to the organization of the factory floor, thus making installation easier. Another advantage is the ease with which the network, laid out under this topology, can be modified. Since each station has independent access, removing or adding a station can be done without disturbing the rest of the network. This is both easier to service and more reliable than either the star or ring. Failure at one station does not prevent the network from continuing its normal functions. Bus topology is a form of distributed control, and this provides for a more direct, reliable and efficient communications system.

4.5 Control and Access

The desired performance and operational requirements for the network application are obtained by utilizing control and access techniques along with network topologies. Control of the network is either centralized at a master node, or distributed at individual nodes. Access to the network is via one of these methods: polling, token passing and contention techniques.

Polling is a form of non-contention technique of channel access. A master node queries each node in turn. If a node has a message, it sends it; if not, the next node is polled. Centrally-controlled polling techniques can be implemented under any topology [15].

Token passing, usually implemented in ring topology, is a form of distributed polling. Token ring technique utilizes a special bit pattern, referred to as a token, which is passed from one node to the next sequentially around the network, referred to as a "logical ring" [16]. A node with a message to transmit has a specific amount of time to remove the token, add a message or remove a message. All other network nodes, during this time, can only listen to the network. Moreover, a token-passing network's performance can be reliabily predicted under any load. Access time is not left to chance, and a network manager can reliably calculate the maximum time required for any station to access the network under any load. Token passing lets the network manager design a system based on priority level. Access to the network is guaranteed within a predetermined amount of time. This features makes token-passing an ideal choice for command, control, process, or other real-time applications [11].

Contention techniques use statistical tools in order to allow nodes to gain access to the channel. Carrier Sense Multiple Access/Collision Detection (CSMA/CD), one of the most publicized methods, requires nodes to "listen" before transmitting. If the network is busy, then the node will either monitor the network continuously or back off for a certain random period of time. If two nodes transmit simultaneously such that there is collision, then both nodes back off for a random time interval before attempting to retransmit. The waiting time is dependent on factors such as network traffic volume, message length, and physical network length. Contention techniques ensure that all nodes are treated with equal priority. CSMA/CD is popular in transaction-oriented environments where traffic is intermittent and access delay can be tolerated. This is not effective for a factory because the traffic in a manufacturing environment tends to be lengthy and constant [3].

4.6 Transmission Medium

The transmission medium is the physical link over which the data are transmitted. There are three kinds of transmission media: i) twisted pair, ii) coaxial cable, and iii) fiber optics.

Twisted pair is the cheapest of the three and is used extensively by telephone companies. It consists of two copper wires twisted together. This medium has the least capacity (bandwith), and is also highly prone to electrical interference. Manufacturing environments need high capacity and, have a high incidence of electrical noise. Placement is another problem. Installing twisted pair near a roof is not practical for factory installation due to the high temperatures found near ceilings, which can cause rapid deterioration of the cable. Floor installation is potentially hazardous. Therefore, twisted cable is not the first choice for a factory [18].

Coaxial cable has far greater capacity than twisted pair. Baseband coaxial cable uses the original "base" frequency to send the signal across. This can be a problem where the system has to compete with electrical noise. This cable type is used to implement small, CSMA/CD-type networks where its single channel is dedicated to communicating data [18]. Broadband coaxial uses broadband signaling and is routinely used for cable TV. This is a mature, stable and reliable technology. The widespread uses of this technology has led to the availability of cables, connectors, and trained installers at reasonable cost. Also, many companies already have CATV systems in place.

Broadband cable has certain major advantages over the other two technologies. First, broadband offers multiple channels and thus capacity to carry many signals simultaneously. Broadband's large bandwidth can support multiple applications over the same cable. Second, signals are encased in a solid shield, and thus are immune to electrical noises, resistant to strong voltage buildup. and require grounding only every 100 ft. [18]. Another advantage is that it is easy to tap and install over long distances. Adding a data network to an existing broadband system requires no wiring modifications. Each network is assigned a different frequency range. Signals are converted into an appropriate frequency range before transmission and are converted back when they arrive at their destination. The control over transmission frequency offered by broadband allows signals to be transmitted at frequencies well beyond the reach of the electrical noise that is found in a factory environment. Over and above all this, broadband has low cost, and is flexible. The above-mentioned advantages make broadband the medium of choice for large, sophisticated, token-passing bus networks, and hence the transmission medium for the factory floor.

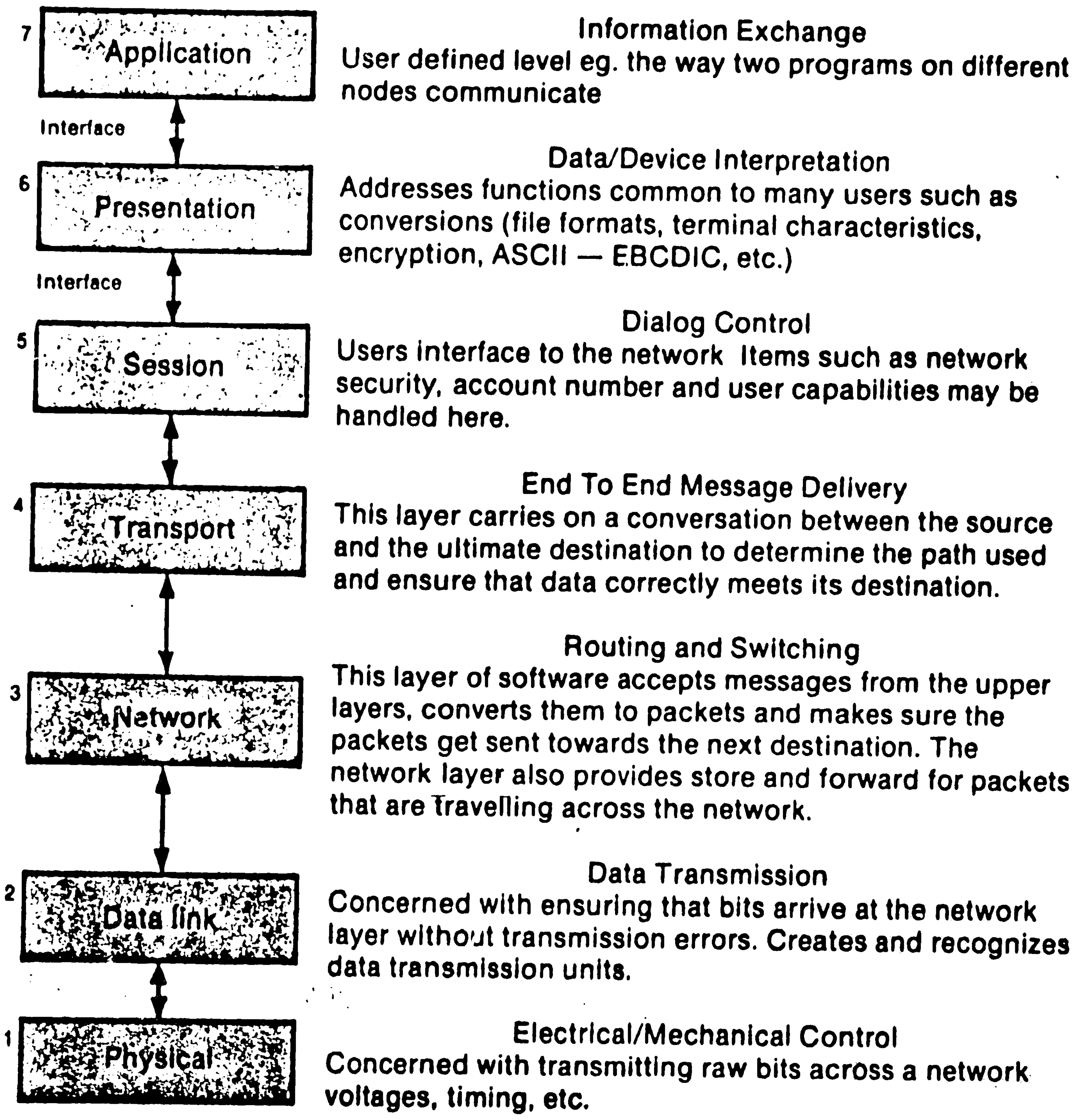
Fiber optics has the greatest potential. It offers enormous bandwith - several optical fibers have the signal-carrying capacity of many hundreds of twisted pair wires. Since the transmission is by means of light rather than electrical pulses, this medium is totally immune to electrical interference. This technology is evolving andso currently is expensive. In addition, it is difficult to tap and repair, which hinders normal network maintenance and addition of new stations.

4.7 Network Architectures

Current computer networks are designed in a highly structured manner. Most networks are organized as a series of layers or levels, in order to reduce design complexity. The purpose of each layer is to offer certain services to the higher levels, while covering up the details of how the offered services are actually implemented. The rules and conventions used in this conversation are collectively known as the layer or protocol [17]. At the physical level, no data are directly transfered from layer n on one machine to layer n on another machine, except in the lowest level. Between each pair of adjacent layers there is an interface. The interface defines which primitive operations and services the lower layer offers to the upper one. Network architecture is the set of layers and protocols.

4.8 ISO Reference Model

As a first step towards standardizing the various protocols, the International Standards Organization (ISO) has developed a proposal. The Reference Model of Open Systems Interconnection (OSI), as defined by ISO, has seven layers.



Information Exchange
User defined level eg. the way two programs on different nodes communicate

Data/Device Interpretation
Addresses functions common to many users such as conversions (file formats, terminal characteristics, encryption, ASCII — EBCDIC, etc.)

Dialog Control
Users interface to the network Items such as network security, account number and user capabilities may be handled here.

End To End Message Delivery
This layer carries on a conversation between the source and the ultimate destination to determine the path used and ensure that data correctly meets its destination.

Routing and Switching
This layer of software accepts messages from the upper layers, converts them to packets and makes sure the packets get sent towards the next destination. The network layer also provides store and forward for packets that are travelling across the network.

Data Transmission
Concerned with ensuring that bits arrive at the network layer without transmission errors. Creates and recognizes data transmission units.

Electrical/Mechanical Control
Concerned with transmitting raw bits across a network voltages, timing, etc.

Figure 4-4: ISO 7-layer reference model [7].

Figure 4-4 shows the physical layout of the ISO-OSI Reference model. The seven layers and their functions are described below [16]:

1. Physical layer is concerned with transmitting raw bits over a communication channel. It performs electrical signalling between nodes on a single LAN.

2. Data link layer's task is to take a raw transmission facility and transform it into a line that appears free of transmission errors to the network layer. This is accomplished by breaking the input data up into data frames, transmitting the frames sequentially, and processing the acknowledgement frames sent back by the receiver. It is up to the data link layer to create and recognize frame boundaries, since layer 1 merely accepts and transmits a stream of bits without any regard to the meaning or structure.

3. The operation of the subnet is controlled by the network layer, also referred to as the communication subnet layer. This layer routes and relays packets between OSI end systems across an arbitrary set of subnetworks while maintaining quality of service (referred to as QOS) appropriate to this communication. Network layer uses a globally unique node address.

4. The host-host layer, also known as the transport layer, accepts data from the session layer and splits it up into smaller units.

5. The user interacts with this layer, called session layer, in order to establish a connection with a process on another layer. After the connection has been made, the session layer manages the dialog in an orderly manner. This layer also provides check pointing and resynchronizing capability.

6. Presentation layer merely performs certain transformations on the data. Library routines, called by the user, perform these functions: ie, transform data from the local system representation into the agreed-upon context and format for interchange via OSI.

7. The contents of the application layer depend on the user.

This is just a model and not a standard. The lack of specifications on how the functions are actually implemented has led to the development of incompatible products. This, in turn, has forced users to choose from a small set of compatible vendors. Boeing and General Motors are currently in the process of standardizing the specifications for the office and the factory floor.

4.9 Networks in Manufacturing

General Motors, in conjuction with McDonnell-Douglas, has proposed a standardized communications protocol based on the above-mentioned ISO-OSI model. This particular protocol, known as Manufacturing Automation Protocol (MAP), is intended mainly as a means of integrating manufacturing-related computer devices. Even though MAP is fairly young, MAP-based broadband networks are expected to dominate the industrial local area network market in the 1990's [13]. MAP is backed by GM and other major manufacturers' such as Hewlett-Packard, Gould Electronics, DEC, IBM, Allen-Bradley, Concord Data Systems, Intel, and Motorola. They have agreed to develop products using MAP specifications. If MAP does become a "standard" then "total integration" would be feasible.

Chapter 5

MANUFACTURING AUTOMATION PROTOCOL

In the early 80's, General Motors (GM) realized that their United States operation was losing its competitive edge to the Japanese. They recognized that part of the solution to their problems lay with integrating multivendor factory automation devices. Productivity improvements basically began with the automated control of single processes such as machines, conveyors, and product test standards. Slowly the orientation of automation was expanded from a single process to that of a functional area, such as material handling, or an entire engine head line. The negative aspect of this trend was that most of these devices did not communicate with each other. Therefore, in order to fully utilize the power of these devices, GM decided to develop a communications standard which would be non-proprietary and widely supported.

GM selected the OSI model as a basis for MAP because of the world-wide acceptance and understanding of this model. Further, GM enacted certain guidelines for the development of MAP. The standard developed had to allow multiple media such as broadband, baseband, and fiber optics. The standard had to represent an open architecture supported by multiple vendors. Finally, emerging national or international standards were to be utilized to implement the OSI layers wherever possible [9].

Computer and control vendors have been supportive of GM's efforts because this will allow them access to a much broader and larger world market than is available to any proprietary or US-based solution. Further, large users throughout the world have realized that they can also benefit from an OSI-based, non-proprietary communications solution. Selection of an international communications standard has another significant advantage in that it represents over 1000 man years of effort by many of the leading communicatiions specialists in the world [5]. GM has shown the feasibility of MAP in a pilot project. GM's Saginaw Steering Gear Division's Factory of the Future project is "totally integrated" via LANs using MAP. This communications network is capable of electronically transmitting all necessary information, downloading programs into machine tools and robots, automatically monitoring all processess and verifying part quality online.

5.1 MAP Specifications

MAP specifications are a selection of currently available standard protocols that are most appropriate for manufacturing automation, combined with a series of interim GM specifications covering areas for which no standards exist. GM and the MAP User's Group, a committee of the Society of Manufacturing Engineers, have made a commitment to replace these "GM specials" with international standards as soon as the standards become available.

The seven layers in MAP have the following specifications [11]:-

Layer 7 (Presentation)	File Transfer per ISO/NBS/MAP Virtual Terminal per ISO/NBS/MAP Directory Services per MAP NetworkManagement per MAP
Layer 6 (Presentation)	MAP Defined (null)
Layer 5 (Session)	ISO/NBS Session plannes
Layer 4 (Transport)	ISO/NBS Transport per class 4 Specification

Layer3 (Network)	ISO/NBS Internet Planned.
Layer2 (DataLink)	IEEE 802.2 Link level procedures
Layer1 (Physical)	IEEE 802.4 Token Bus in Baseband or Broadband.

Standards specification for layer 6 and layer 7 are non-existent at this time. The specifications above (for layers 6 and 7) are "GM specials". MAP and Technical Office Protocol (TOP), a standard developed by Boeing Computer Services for "office use", will be identical at layers 2 through 5 with a common layer 7 protocol, FTAM (File Transfer and Management). Level 6, at this time, is null in either standard. Thus, TOP will be able to a transfer information to MAP network and MAP will be able to a transfer information to TOP network easily. This will enable the "office" entity to communicate with the "manufacturing" entity.

Critical standards to be determined involve issues related to network management. Among those are how errors are corrected, how information will move to devices, how devices will get that information, who talks first, and who has control of session.

Network management is a catchall phrase for a number of features vital to the successful operation of a network. At present, MAP 2.1 specifies only the basic requirements for interfaces to various OSI layers that enable someone to read statistics on the performance of an individual layer. The means by which a vendor reads the statistics are not yet defined. As a result, there are no useable means by which a fault can be traced across a network. For example, if a network interconnecting an IBM and an AT&T machine suddenly stops working, there is no mechanism for sending diagonostics messages to the two machines to find out which protocol in which machine is not transmitting data. The only option is to shut down the system and restart it.

Another area of network management is version control. Version control is the means by which different versions of protocols created by different vendors can identify when changes have been made. At present MAP does not specify any standards for this. Serious problems can result if suppliers of network components change their installations at random intervals. No standard have been defined at the present time.

MAP Backbone Architecture supports MAP End Systems which implement MAP's version of OSI protocols (layer 6/7) and can communicate with other MAP End System either at the same plant or at remote sites. MAP specifies two systems (bridges and router) which can be used to interconnect parts of a plantwide MAP subnetwork. For connecting non-OSI networks, MAP specifies a device(gateway). Figure 5-1 is an example of a prototypical MAP network.

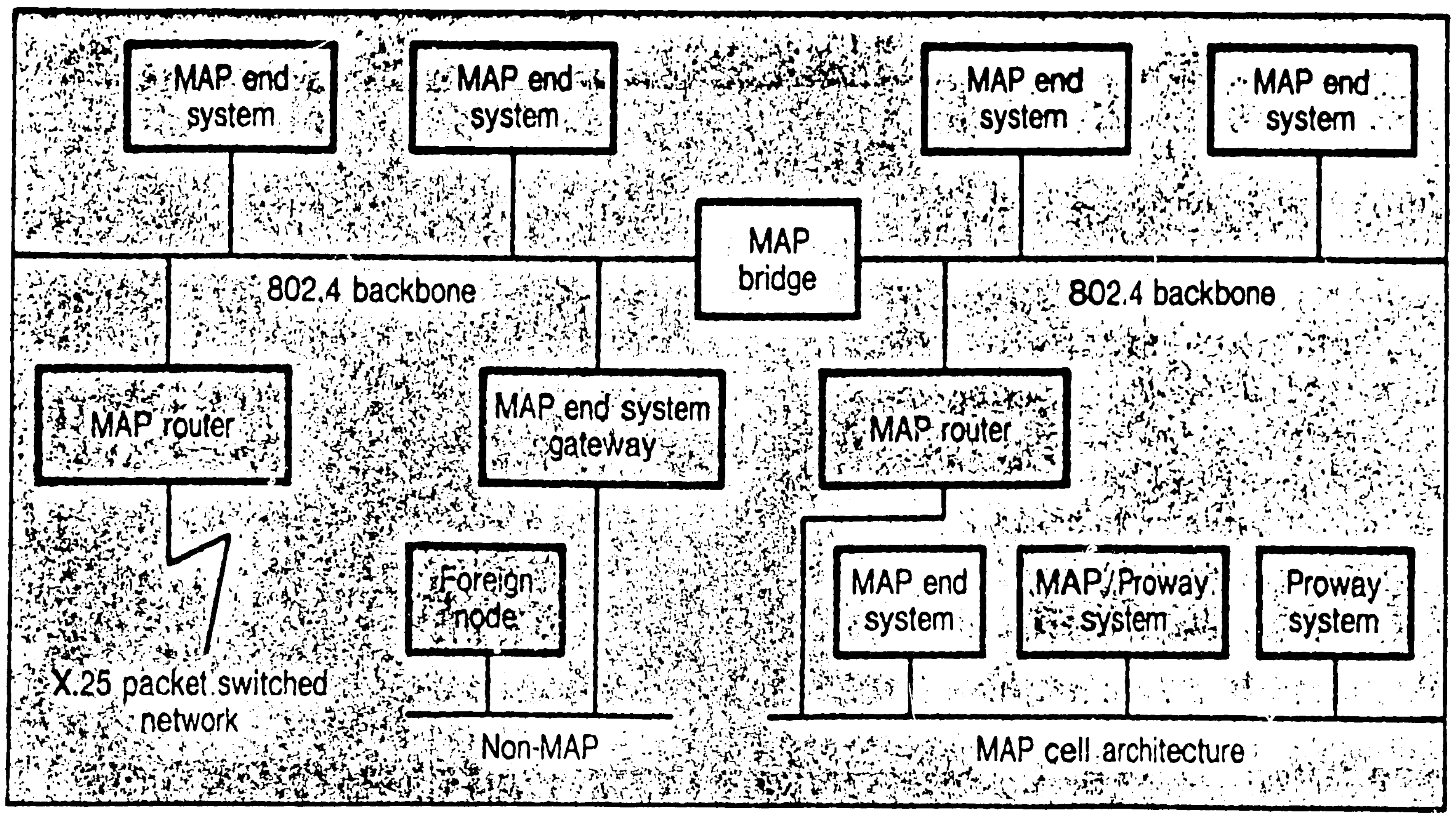


Figure 5-1: Prototypical MAP network [5].

Under the present specifications, broadband-based MAP networks have the capacity to transmit at a rate of 10Mbits/sec. This is the rate at which data can flow through the co-axial cable. This is not reflective of the true "communications" rate because it doesn't take into account the time needed by the computer to access data from memory or disk. Users should be prepared to obtain actual rate in the range of 1-100 Kbytes/sec., which is about 1/10th the maximum capacity. MAP has a lot of potential and will play a major role in the future.

5.2 MAP Justification

In order to maintain one's competitive edge, a manufacturing company must acquire, use and transmit timely information. In the past, numerous types of transmission media and standards along with the multiplicity of communications media and protocols that are now available generated problems when it came time to connect different types of control equipment and other intelligent devices. GM justifies a standard communications protocol by pointing out that installing separate cables for dissimilar intelligent devices is expensive, and along with cost of protocol conversion is something that can be avoided.

Another reason to "go" with MAP is the amount of research being conducted in that area. National Bureau of Standards (NBS) is working co-operatively with about 30 computer and semi-conductor manufacturers, as well as General Motors and Boeing Computer Services in a co-operative project to demonstrate the implementation and interaction of MAP and TOP. MAP is being adopted as the standard by major Japanese and European manufacturers such as Fanuc, NEC, Toyota Motors, Suzuki Motors, and Ferranti. MAP also provides for a wide-range of configuration possibilities. In various configurations, MAP will permit communications between GM's 40,000 computers and other intelligent devices, as well as its 2800 robots and 20,000 programmable controllers.

5.3 MAP Benefits

It has been estimated that within the automotive industry, automated factories, made possible by MAP, will lead to savings of up to $2,000 per car, besides significant improvements in quality and reductions in the lead time for introduction of new models of up to 2 years. On the factory floor , information that once was acquired by the five senses and communicated by voice and paper, can now be gathered, analyzed, and transmitted at the speed of light. MAP-based LANs simply provide the most economical way to bring this about.

MAP attempts to increase productivity by developing a set of standarized specifications that will allow a plant's entire range of intelligent machines, from CNC machines tools to mainframe computers to communicate. Ford, which has recently endorsed MAP, expects lower floor systems costs as need for multiple cables and custom networking software is reduced. Ford also expects improved flexibility and adaptability of production systems to meet changing demands, the expanded choice in suppliers due to communications compatibility, and shortened lead time in designing and implementing integrated manufacturing systems.

5.4 Alternatives to MAP

As promising as MAP might sound, it presents problems in terms of long-range objectives. At present, many companies are designing machine controller communications to conform to MAP. Hardware and software systems of many programmable controllers, robots, and other machine tools will have to be overhauled and this cost will be passed onto the consumer. In order to ensure compatiblity, product must be tested. Conformance tests are typically contracted by vendors, and many vendors pass the cost onto consumers. The test cycle to prove conformance of a product with the MAP standard is long and expensive. Media control unit, the device which links each "computer device" to the LAN, currently costs about $10,000 each. All these imply that MAP is going to be an expensive proposition.

Another major problem with MAP is the speed [13]. The present design is based on high connectivity and absolute reliablity of data transfer for a great variety of equipment and computer types and a large number of devices on the LAN. This criterion results in a transaction response time of 1-3s. If a process has to be controlled on a real-time basis then this response time has to be brought down to 5-20ms. Currently, this is not of much concern because most real-time control is performed at a local level: by a robot, for example. In the future, when the cell controller takes on more responsiblities, response time becomes a crucial isssue.

An alternate approach to total MAP compatibility has been suggested by Peter Cornwell of Texas Instruments [13]. The alternative idea is to spilt the functional requirements of plant communications into two distinct classes, using different network implementations, to provide enhanced performance at the cell-level, but preserving MAP compatibility of the OSI 7 interface with a plant backbone. The cell-level network could be either OSI-based or proprietary. This allows a structure of cell-level sub-networks to be introduced for local real-time control and then to provide gateways between these cells or local zone networks and a plant level backbone network. This is a solution which should be given serious consideration.

5.5 Future of MAP

MAP is strong technically and it has the support of major vendors. Like any evolving technology, the faults are being worked on and will eventually be eliminated. The cost of the system will also come down as more users adopt it. Moreover, there is no competing set of standards that is widely accepted. MAP's compatibility with Boeing's Technical Office Protocol makes it the best solution for the factory.

Chapter 6
CONCLUSION

Competition from the Japanese and European manufacturers has finally forced American manufacturers to confront reality and find ways to increase productivity. For the past decade, automation of individual manufacturing processes has been touted as a means of remaining competitive. Many innovative companies took the advice and started a variety of automation projects. This non-systematic approach has led to the creation of "island of automation".

In the past, lower-level managers were allowed to buy their own computerized equipment. This has to change. Standarization implies company-wide buying policy. Upper level management has to get involved. At present, many managers cannot financially justify Modern Integrated Manufacturing (MIM) technology based on traditional criteria such as Return on Investment (ROI) and Net Present Value (NPV). Short term financial outlook must be replaced with strategic benefits, such as flexibility, reduced new product development lead time and long term competitive success. When viewed as a total program, MIM can be financially justified by ROI or NPV formulas.

Currently, top management never gets to see a total MIM program, its total costs, and particularly its total benefits. Top managers are isolated from the changes in the technology and are usually content with the present status. Most executives are not sufficiently involved in their core business--manufacturing. This leads to the decline in the firm's competitiveness. Junior-level management can change this by helping develop an overall strategic plan and thus refocusing the strategic importance of manufacturing.

Since networks play a vital role in MIM, every company should consider implementing this technology. At this juncture, MAP seems to be the only viable set of standards in networking. This is another issue to be explored by companies desiring to improve productivity.

America can regain its leadership if its business leaders would shed their fears about computer technology and also look at long-range benefits instead of looking at short-term profits.

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